VOLTAGE REGULATION WITH REACTIVE POWER CONTROL OF AN OPTIMIZED 30-BUS POWER SYSTEM

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ABSTRACT
In recent years, energy, environment, right-of-way and cost problems and 'quality need' have delayed the construction of both generation facilities and new transmission lines. These problems have necessitated a change in the traditional concepts and practices of power systems. The objective of the work presented in this report is to make an EP based algorithm for solving the optimal power flow (OPF) problem without and with compensating device. The objective in the OPF problem formulation is the minimization of total cost of real power generation. Taking into consideration power balance equality constraints, limits on the control variables namely active power generations, controllable voltage magnitudes, limits on the dependent variables namely reactive power generations and load bus voltage magnitudes and limits on MVA line flows as the inequality constraints. Also, with the technique of series compensation, the quality i.e. voltage and reactive power loss is regulated.

Keywords - **Optimal power flow (OPF), EP based model. Capacitor, MVA, constraints**

INTRODUCTION
Throughout the entire world, the electric power industry has undergone a considerable change in the past decade and will continue to do so for the next several decades. In the past the electric power industry has been either a government-controlled or a government-regulated industry which existed as a monopoly in its service region. All people, businesses, and industries were required to purchase their power from the local monopolistic power company. This was not only a legal requirement, but a physical engineering requirement as well. It just didn't appear feasible to duplicate the resources required to connect everyone to the power grid.
A first comprehensive survey regarding optimal power dispatch was given by H.H.Happ [1] and subsequently an IEEE working group [30] presented bibliography survey of major economic-security functions in 1981. Thereafter in 1985, Carpentair [31] presented a survey and classified the OPF algorithms based on their solution methodology. In 1990, Chowdhury [32] did a survey on economic dispatch methods. In 1999, J.A.Momoh *et al.* [5] presented a review of some selected OPF techniques. In this paper, a review of following optimization methods has been presented. (1)Linear Programming (LP) method, (2) Newton- Raphson (NR) method, (3) Quadratic Programming (QP) method, (4) Nonlinear Programming (NLP) method, (5) Interior Point (IP) method and (6) Artificial Intelligence (AI) methods.

Earlier, a wide variety of optimization techniques have been applied to solving the OPF problems such as nonlinear programming (NLP), quadratic programming (QP), linear programming, Newton-based techniques, and interior point methods. But, because of certain drawbacks, such as insecure convergence properties, algorithmic complexity, and convergence characteristics. These, local optimization techniques are not suitable for such a problem. Newton's method is well-known in the area of power systems. It has been the standard solution algorithm for the power flow problem for decades [28]. A good reference for the theory of Newton's method is a book by Luenberger [29], which describes Newton's method as well as its quadratic convergence properties. There are more classical method has been already discussed earlier. A number of evolutionary inspired optimization techniques were developed i.e. Bremermann in 1962, Jason Yuryevich in 1999, Weerakorn Ongsakul in 2004, Latha Kumari in 2004, R Gnanadass in 2004,Dr. Y R Sood in 2005,Zulmar S. Machado Jr in Aug,2005, M Basu in Sep,2005,M.A.Abido in July,2006. Here we discuss a comparison between classical methods and our EP method.

The aim of the proposed work is to apply evolutionary programming (with Gaussian Method) technique to improve the optimal power flow solution and to increase quality by voltage regulation and reactive power control. Also, series capacitor is being used to improve the power transfer capability of the system with a marginal increase in cost.

I. PROBLEM FORMULATION OF OPF WITH SERIES CAPACITOR

The objective of an Optimal Power Flow (OPF) algorithm is to find the steady-state operation point of a generation transmission system, which minimizes a pre specified cost function and meets a set of operational and/or security constraints. For optimal active and reactive power dispatch the objective function that is total generation cost and other objectives may include minimization of transmission losses and voltage level optimization. In case of active power OPF, the main conventional control variables are MW generations based on minimum generation cost. If some predefined transmission line power flows are controlled at specified values, it may cost higher with the generation schedule. OPF algorithms are among the tools present in many Energy Management Systems (EMS) and their usefulness is increasingly being recognized by power utilities due to increased presence of independent power producers combined with deregulation of the power industry. Hence there is an urgent need for optimal and sophisticated power flow control i.e., solution to OPF incorporating FACTS devices. The reactive power compensation of AC transmission systems using fixed series capacitors is applied here to solve some of the above problems associated with AC networks. Here, series capacitor is used to improve the reactive power capability of the line without causing a major increase in the cost.

II. REACTIVE POWER COMPENSATION IN ELECTRIC POWER SSTEM

Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads (residential, commercial and industrial sectors) impose real and reactive power demand, depending on their characteristics. Real power is converted into "useful" energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of real power to loads. In our study voltage regulation with reactive power system.

The reactive power is essential for creating the needed coupling fields for energy devices. It constitutes voltage and current loading of circuits but does not result in average (active) power consumption and is an important component in all ac power networks. Reactive power control for a line is often called Reactive Power Compensation. External devices or subsystems that control reactive power on transmission lines are known as Compensators. The objectives of line compensation are

- To increase the power transmission capacity of the line, and/or
- To keep the voltage profile of the line along its length within acceptable bounds to ensure the quality of supply to the connected customers. Because reactive power compensation influences the power transmission capacity of the connected line, controlled compensation can be used to improve the system stability by changing the maximum power- transmission capacity.

III. OPF MATHEMATICAL MODEL

The objective function to be minimized is given below:

$$f = \sum_i F_i(Pg_i)$$

Where $F_i(Pg_i) = a_i P_i^2 + b_i P_i + c_i$

This is the sum of operating cost over all controllable power sources.

$F_i(Pg_i)=$ Generation cost function for Pg_i generation at bus i. The cost is optimized with the following constraints. The inequality constraint on real power generation at bus

Our Study is focus on optimal power flow program (OPF) by using EP based technique, as a tool for solving this type of optimization problem. The OPF is a natural choice for addressing these concerns because it is basically an optimal control problem. The OPF utilizes all control variables to help minimize the costs of the power system operation. It also yields valuable economic information and insight into the power system. In these ways, the OPF very adeptly addresses both the control and economic problems. After creating the OPF program, the user-interface and simulation problems may also be addressed by implementing the OPF into a power system simulator. In this way, the results of the economic and control operations of the OPF can easily be utilized by the user of the program.

Anant Gupta, Sarita / International Journal of Engineering Research and Applications (IJERA)
ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 2,Mar-Apr 2012, pp.1666-1671

IV. INEQUALITY CONSTRAINTS

The inequality constraints of the OPF reflect the limits on physical devices in the power system as well as the limits created to ensure system security. Physical devices that require enforcement of limits include generators, tap changing transformers, and phase shifting transformers. This section will lay out all the necessary inequality constraints needed for the OPF implemented in this thesis. Generators have maximum and minimum output powers and reactive powers which add inequality constraints.

$P_i^{min} \leq P_i \leq P_i^{max}$

$V_i^{min} \leq V_i \leq V_i^{max}$

$\varphi_i^{min} \leq \varphi_i \leq \varphi_i^{max}$

where, P_i^{min} and P_i^{max} are the minimum and maximum generator limits, for generator i.

V_i^{min} and V_i^{max} are respectively minimum and maximum voltages at bus i.

φ_i^{min} and φ_i^{max} are respectively minimum and maximum phase angle at bus i.

V. RESULT AND DISCUSSION

Thus, it is proved that EP based OPF gives better cost effective optimal solution, which is given in table (a, & b). We can see that after applying EP model the optimal power cost is minimum.

We discussed above study with the help of ours calculated data by without and with using series capacitor; the compensation is done on bus line no 13-12. The value of fixed capacitor used is 0.1562 p.u (table1.1) Thus, from tables (1.2 a & b) according to our data's without and with series capacitor a variation in voltage at different buses after the implementation of series capacitor. Also, the increase in power transfer is noticed at different lines after the application of series capacitor. Thus, the series capacitor has been successfully applied in the power system. The role of series capacitor is to improve the power transfer capability of the line with a marginal increase in cost, which has been successfully implemented in the power system. Here, a fixed value of capacitance is applied on different line numbers and the reactive power capability of line has been improved with a marginal increase in cost.

Table (a): Optimal generation before applying EP

Generator	MW
1	177.6885
2	38.4613
3	25.7691
4	17.6922
5	16.1538
6	16.9006

Total cost for dispatch is **833.27 $/hr**.

Table (b): Optimal generation after applying EP

Generator	MW
1	229.571
2	20.00
3	15.00
4	10.00
5	10.00
6	12.00

Total cost for dispatch is **806.9779 $/hr**.

Table: 1.1 Voltage magnitudes on different line without and with application of series capacitor

Line no.		Voltage mag.(before)	Voltage mag.(after)
13-12	13	1.088	1.088
	12	1.046	1.048
8-6	8	1.023	1.023
	6	1.022	1.023

4-3	4	1.027	1.027
	3	1.032	1.033
4-2	4	1.0270	1.0271
	2	1.033	1.033

4		-7.6	-1.6	0		
	2	-30.471	5.6	30.981	0.532	-2.284
	3	-53.346	5.751	53.655	0.361	0.145
4		-7.6	-1.6	0		
	2	-30.471	5.6	30.981	0.532	-2.284

Table: 1.2 Line flows and losses without and with application of series capacitor (a)

Line flows and losses(before)						
--Line--		Power at bus and line flow			---Line loss--	
from	to	MW	Mvar	MVA	MW	Mvar
13		16.901	33.35	0		1.654
	12	16.901	**33.377**	37.412	0	
12		-11.2	-7.5	0		2.175
	4	-27.225	**13.692**	30.474	0	1.654
11		16.154	25.547	0		1.177
	9	16.006	**20.132**	25.719	0	
28		0	0	0		1.322
	27	18.048	**8.848**	20.1	0	-4.438
8		-12.308	5.47	0		
	6	-14.227	**5.48**	15.246	0.027	-0.846
6		0	0	0		
	2	-40.981	**6.928**	41.563	0.978	-0.983

(b)

Line flows and losses(after)						
--Line--		Power at bus and line low			---Line loss--	
from	to	MW	Mvar	MVA	MW	Mvar
13		16.901	36.242	39.988		
	12	16.901	**36.256**	40.001	0	1.621
12		-11.2	-7.5	13.479		
	4	-28.113	**14.258**	31.522	0	2.15
11		16.154	23.522	28.534		
	9	16.154	**23.525**	28.537	0	1.309
28		0	0	0		
	27	18.41	**9.015**	20.499	0	1.302
8		-12.308	8.984	15.238		
	6	-14.98	**9.312**	17.639	0.037	-0.874
6		0	0	0		

	2	-43.551	**8.425**	44.359	1.116	-0.945
4		-7.6	-1.6	7.767		
	2	-29.178	4.807	29.572	0.485	-2.426
	3	-56.076	**6.662**	56.47	0.4	-0.349
4		-7.6	-1.6	7.767		
	2	-32.436	**6.737**	33.128	0.61	-2.259

VI. CONCLUSION

The Evolutionary Programming (EP) based Optimal Power Flow problem has been explored and tested with and without compensating device. The results show that a simple evolutionary based algorithm can give a best result using only simple evolutionary operations such as mutation. Thus, in large-scale system, where the number of constraints is very large, it is necessary to use the methodology like EP which results to give optimum solution and capable of handling such type of problems. The Evolutionary Programming based technique without and with compensating device is applied and validated on the IEEE30 bus system. The compensating device included in this study is the series capacitor. The role of series capacitor used here in the problem is to improve the power transfer capability of the line while keeping a marginal variation in cost.

VII. FUTURE WORK

In future we validate our results with respect to the work done in this study, by using the following assumptions:-

- Problem can be solved by replacing series capacitor by a series connected Flexible AC Transmission Systems (FACTS) device. For a desired value of compensation, power injection model parameters of the compensating FACTS device can be evaluated.
- Instead of using Evolutionary Programming, any other Genetic algorithm based tool can be implemented.

ACKNOWLEDGEMENTS

I hereby thank to my supervisor and my friends for help me doing such a work on power system.

REFERENCES

[1] H. H. Happ, “Optimal power dispatch-A comprehensive survey”, *IEEE Trans. Power Apparat. Syst.*,vol. PAS-90, pp. 841-854, 1977.

[2] IEEE working group, “Description and bibliography of major economic-security functions part-II and III, *IEEE Trans. Power Apparat. Syst.*, vol. PAS-100, pp. 215-235, 1981.

[3] .A. H. Wright; et al.,"Implicit Parallelism," Proceedings of the Genetic and Evolutionary Computation Conference, 2003.

[4] A. J. Wood and B. F. Wollenberg, “Power Generation Operation and Control,” New York, NY: John Wiley & Sons, Inc., pp. 39,517, 1996.

[5] B. H. Chowdhury and S. Rahman, “A review of recent advances in economic dispatch,” IEEE Trans Power Syst. 54, 1990.

[6] Coello, C. D. Veldhuizen, G. Lamont, ” Evolutionary Algorithms for Solving Multi-Objective Problems,” Kluwer Academic Publishers, 2002.

[7] D.B.Fogel, “Evolutionary Computation: Toward a New Philosophy of Machine Intelligence,” IEEE Press, USA, 1995.

[8] Deb, and A. K. Kumar, “Real-coded genetic algorithms,” 1995.

[9] D. I. Sun, B. Ashley, B. Brewer, A. Hughes and W. F. Tinney, “Optimal Power Flow by Newton Approach,” IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103, pp. 2864-2880, Oct. 1984.

[10] D. M. Sauter, “Chapter 9, voltage fluctuations on power systems,” Distribution Systems, 1965.

[11] Dr. Y R Sood and Dr. N P Padhy, ”A new Evolutionary Programming based approach for

Optimal Selection of Wheeling options," IEE(1) Journal, pp.146-153, Feb. 2005.

[12] G. Kjellstrom, "On the Efficiency of Gaussian Adaptation". Journal of Optimization Theory and Applications, Dec. 1991.

[13] H.J. Bremermann, "Optimization through Evolution and Recombination," Self Organization Systems, Spartan Books, Wasington, D.C., pp. 93-106, 1962

[14] H. Rudnick, "Pioneering electricity reform in South America," IEEE Spectrum, Vol. 33, No. 8, pp. 38-44, Aug. 1996.

[15] H.T. Yang, P.C. Yang and C.L. Huang, "Evolutionary programming based economic dispatch for units with non-smooth fuel cost functions," IEEE Trans. Power System. 11, 1996.

[16] H. W. Dommel and W. F. Tinney, "Optimal Power Flow Solutions," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, pp. 1866-1876, Oct. 1968.

[17] J. Carpienter, "Contribution e l'étude do Dispatching Economique", Bulletin Society Française Electriciens, Vol. 3, Aug. 1962.

[18] Jason Yuryevich, Kit Po Wong, "Evolutionary programming based optimal power flow algorithm", IEEE Transactions on Power Systems, Vol. 14, No. 4, Nov. 1999.

[19] Jong-Hwan Kim, and Hyun Myung, "Evolutionary programming techniques for constrained optimization problems", IEEE Transactions on Evolutionary Computation, Vol. 1, No.2.

[20] J. S. Hedin and L. H. Paulsson, "Application and evaluation of a new concept for compact series compensation for distribution networks," 12th International Conference on Electricity Distribution, vol. 1. Birmingham, UK, May 17–21, Conf. Publ. no. 373, pp. 1.22/1–5, 1993.

[21] J.W. Butler and C. Concordia, "Analysis of series capacitor application problems," AIEE Trans., pp. 975–988, 1937.

[22] Hadi Sadat, "Power system analysis," McGraw hill publication, New Delhi, Edition-1997.

[23] K. Deb,"Multi-Objective Optimization Using Evolutionary Algorithms, Wiley" 2001.

[24] K. Kuppusamy and R. P. Kumudini Devi,"Evolutionary programming based security constrained optimal power flow," 2000.

[25] K.P.Wong and J.Yuryevich, "Evolutionary-programming-based algorithm for environmentally-constrained economic dispatch," IEEE Trans. Power Syst., 1998.

[26] Latha Kumari, "Evolutionary Programming based Economic Power Dispatch Solutions with Independent Power Producers," IEEE International Conference on Electric Utility deregulation, Restructuring and Power Technologies, pp. 172-177, 2004.

[27] W. F. Tinney and C. E. Hart, "Power Flow Solution by Newton's Method," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-86, No. 11, November 1967, pp. 1866-1876.

[28] D. G. Luenberger, *Linear and Non-Linear Programming*, Reading, MA: Addison-Wesley Publishing Company, 1984, pp. 295-392,423-450.